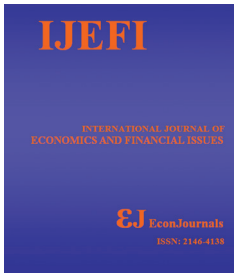

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Determinants of Fourth Industrial Revolution Technology Adoption in Zimbabwean State Universities: A Technology-Organization-Environment Framework Analysis

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ABSTRACT

This study investigates the determinants of Fourth Industrial Revolution (4IR) technology utilisation in Zimbabwean state universities using the Technology-Organisation-Environment (TOE) framework. A quantitative research design was adopted, using structured questionnaires to collect data from 163 respondents across seven public universities. Data analysis involved descriptive statistics, reliability testing, exploratory factor analysis, and multiple regression. Findings reveal that all three TOE dimensions significantly predict 4IR utilisation ($P < 0.001$). Technological readiness, especially perceived ease of use, tool availability, and usefulness was the strongest driver. Organisational factors, including leadership commitment and digital culture, were also critical, while environmental enablers such as supportive policy and stakeholder collaboration showed a weaker but significant effect. Demographic results indicated high educational attainment and awareness of 4IR, yet persistent disparities in access, particularly among students. The study underscores the need for integrated strategies that combine infrastructure investment, institutional capacity building, and enabling policy frameworks. It contributes to TOE literature in resource-constrained higher education systems and offers practical insights for advancing digital transformation in the Global South.

Keywords: Fourth Industrial Revolution (4IR), Technology-Organization-Environment, State Universities, Digital Transformation, Zimbabwe
JEL Classifications: O33, I23, L86, O32

1. INTRODUCTION

In Zimbabwe, State Universities are fundamental to the higher education system and key contributors to national development (Mawonedzo et al., 2020). Higher education institutions in Zimbabwe play a crucial role in the country's socio-economic development, fostering innovation, and promoting knowledge creation (Bonga, 2024; Government of Zimbabwe Priority Programmes, 2019). These institutions are pivotal in shaping the nation's future by providing advanced education, conducting research, and engaging with the community (Mawonedzo et al., 2020; Mahlangu et al., 2018). Dzingirai (2025) highlighted that Zimbabwean universities and colleges are hubs of research, innovation and development, contributing to new knowledge and technological advancements. Institutions often serve as innovation hubs where new ideas are developed and tested, contributing to technological and social progress (Mutandavari et al., 2023; Musungwini & Dhliwayo, 2024; Togo and Gandidzanwa, 2021). With a mandate to provide quality education, conduct research, and promote innovation, these institutions play a vital role in shaping the country's human capital, driving economic growth, addressing societal challenges and preparing individuals for the demands of the 4IR-driven economies (Garwe and Zimbabwe, 2014; Dias and Tebaldi, 2012).

However, higher education institutions in Zimbabwe face a myriad of challenges that impact their ability to deliver quality education, conduct meaningful research, and contribute to national development (Mupa, 2020). These challenges are multifaceted, involving economic, infrastructural, technological, and socio-political factors (Majoni, 2014). Chinyoka and Mutambara (2020)

stated that the reduced government financial support due to economic constraints impacts the ability of institutions to maintain and improve infrastructure, pay staff, and support student services. The country has faced significant economic challenges, including hyperinflation, currency instability, and resource constraints, which have impacted the funding and development of its higher education sector (Chiwodza et al., 2023). Lack of funding for research projects limits the ability of institutions to contribute to knowledge creation and innovation (Teferra et al., 2013). Majoni (2014) asserts that skilled academics and professionals often leave Zimbabwe for better opportunities abroad, leading to a shortage of qualified staff. Moreover, some institutions face challenges in recruiting and retaining adequately qualified faculty members due to low salaries and poor working conditions (Chiwodza et al., 2023). However, some of these challenges are exacerbated by political interference in the administration and governance of institutions which undermines their autonomy and academic freedom. According to Yingi et al. (2022), many institutions are not adequately preparing students with the skills necessary for the 4IR job market, such as digital literacy, data analytics, and AI.

Despite these challenges, the adoption of 4IR technologies presents significant opportunities for state universities in Zimbabwe. Enhanced learning outcomes can be achieved using AI-driven personalized learning platforms that cater to individual student needs (Yingi et al., 2022). Virtual and augmented reality can provide immersive learning experiences that go beyond traditional classroom settings (Kiryakova, 2020). Furthermore, the use of big data analytics can enable universities to make informed decisions about resource allocation, student support services, and curriculum development (Webber and Zheng, 2020). The successful integration of 4IR technologies can also drive research and innovation, positioning Zimbabwean universities as key players in the global academic and research community (Dosso et al., 2021). Collaboration with industry and international partners can facilitate knowledge exchange, access to cutting-edge technologies, and opportunities for joint research initiatives. Considering the need for strategically and effectively navigating the 4IR landscape to enhance the quality of education, foster innovation, and contribute to the broader development goals of Zimbabwe.

The objective of this paper is to explore the extent of utilisation of 4IR technologies among state universities in Zimbabwe. This study contributes to both policy and academic discourse on how Zimbabwean universities can effectively harness 4IR technologies to enhance institutional performance and support national development goals. The structure of this paper is organized as follows: Following this introduction, the literature review section. The methodology section outlines the research design, sampling techniques, data collection methods, and analytical approaches employed in the study. The results and discussion section presents the key findings from the fieldwork, interpreting them in relation to existing literature and the research objectives. The conclusion summarizes the main insights, highlights practical implications for policymakers and university administrators, and suggests areas for future research. This structured approach ensures a comprehensive and coherent exploration of the utilisation of 4IR technologies in Zimbabwean state universities.

2. LITERATURE REVIEW

The 4IR signifies a transformative fusion of physical, digital, and biological systems, impacting numerous sectors including higher education (Schwab, 2016). Technologies such as artificial intelligence, blockchain, the Internet of Things, big data analytics, and robotics hold substantial potential to revolutionize teaching, research, administration, and community engagement within universities (Aoun, 2017; Yusuf et al.,2020). As these institutions navigate the integration of 4IR technologies, understanding the determinants of their utilisation is essential for effective digital transformation (Mhlanga & Moloi, 2020).

Within the African higher education landscape, persistent infrastructural deficits, constrained financial resources, and skills shortages are frequently cited barriers to technology uptake (Chigona and Chigona, 2013; Masinde & Roux, 2020; Mtebe and Raisamo, 2014). Zimbabwean universities confront similar challenges, compounded by economic instability and regulatory uncertainty, which limit their capacity to fully exploit 4IR technologies (Mhembwe and Mavhungu, 2020). Nevertheless, strong leadership commitment and supportive policy frameworks have emerged as crucial enablers, fostered institutional readiness and encouraged staff engagement with digital initiatives (Ifinedo, 2011). Recent studies emphasize the pivotal role of human capital development, especially digital literacy and targeted training, in promoting effective 4IR utilisation in higher education (Olaitan et al., 2024; Zhou et al., 2022). Zimbabwe's Education 5.0 policy, which underscores innovation, industrialization, and technology integration, offers a conducive policy environment; however, its success depends heavily on adequate infrastructure and sustainable funding (Gudyanga, 2021; Government of Zimbabwe Priority Programmes, 2019). Despite the growing interest in 4IR adoption, empirical research exploring the interplay of technological, organizational, and environmental factors within Zimbabwean state universities remains limited. Much of the existing literature is conceptual or descriptive, lacking systematic, context-specific investigations.

The Technology-Organization-Environment (TOE) framework (Tornatzky and Fleischer, 1990) provides a robust lens for analysing technology adoption in organizational contexts. It identifies three interrelated domains influencing adoption decisions: the technological context (availability, compatibility, and complexity of technologies), the organizational context (leadership, culture, resources, and institutional readiness), and the environmental context (regulatory pressures, policies, and competitive dynamics) (Awa et al., 2016). This framework has been widely applied in studies on digital technology adoption, including those examining 4IR in higher education globally (Chaka, 2023; Baker, 2012; Oliveira and Martins, 2011). This study applied the TOE framework to comprehensively assess the determinants of 4IR utilisation, thereby enriching theoretical discourse and providing actionable insights for policymakers and educational leaders. The study developed the following Hypothesis:

- H_1: Technological factors positively influence the utilisation of 4IR by State University in Zimbabwe
- H_2: Organisational factors positively influence the utilisation

of 4IR by State University in Zimbabwe

- H_3: Environmental factors positively influence the utilisation of 4IR by State University in Zimbabwe.

3. METHODOLOGY

This study employed a quantitative research design utilizing structured questionnaires to investigate the determinants of 4IR utilisation by state universities in Zimbabwe (Mthombeni, 2024). The quantitative approach enables systematic measurement and statistical analysis of factors influencing 4IR adoption across multiple stakeholder groups. The target population included university administrators, faculty members, IT and technical staff, and students from the 7 state universities in Zimbabwe. These groups were selected to provide diverse perspectives on the strategic, operational, technical, and experiential aspects of 4IR utilisation. A stratified simple random sampling technique was employed, with stratification based on university age to ensure representative participation across institutions. Using Yamane's formula for sample size determination, a total of 250 questionnaires were distributed. Out of these, 163 participants provided usable feedback, representing the final sample for analysis. This sample size aligns with benchmarks from recent studies on 4IR adoption in higher education (Cele et al., 2023; Al-Riyami et al., 2023).

A structured questionnaire was developed guided by the TOE framework (Abed, 2020). The questionnaire included closed-ended items measured on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), covering constructs related to technological readiness, organizational factors, environmental influences, and the extent of 4IR technology utilisation. A cover letter accompanied the questionnaire, outlining the study objectives, assuring confidentiality, and seeking voluntary participation. Questionnaires were administered both electronically and in printed form to maximize response rates and accessibility. Data collection spanned 4 weeks, with follow-up reminders sent to improve participation. Completed questionnaires were coded and analysed using SPSS (version 22). Descriptive statistics (frequencies, means, and standard deviations) summarized participant demographics and responses. Multiple regression analysis was conducted to test the influence of technological, organizational, and environmental factors on the utilisation of 4IR technologies. Prior to conducting the analysis, diagnostic tests were performed to verify the assumptions of normality, linearity, homoscedasticity, and absence of multicollinearity, thereby ensuring the validity and robustness of the findings (Lovia et al., 2024; Mardiatmoko, 2024). The researcher has successfully completed ethical training at North-West University (NWU) and affirms the absence of any conflicts of interest related to this study. Ethical clearance for the study was granted by the NWU Ethics Committee.

4. RESULTS

The robustness of the measurement model was evaluated prior to hypothesis testing to ensure the reliability and validity of the constructs underpinning this study.

4.1. Construct Validity

Construct validity was first examined through exploratory factor analysis (EFA). Principal Component Analysis with varimax rotation confirmed the factorial structure of the measurement instrument. The Kaiser-Meyer-Olkin index indicated adequate sampling adequacy (KMO = 0.79), while Bartlett's test of sphericity (χ^2 [120] = 453.22, P < 0.001) confirmed the suitability of the data for factor analysis. Three factors emerged in alignment with the TOE framework, collectively explaining 68.4% of the total variance (Legesse et al., 2024). All standardized factor loadings exceeded the recommended threshold of 0.60, with no evidence of substantial cross-loadings, thereby supporting both convergent and discriminant validity.

4.2. Reliability Analysis

Following the extraction of latent factors, the internal consistency reliability of the constructs was assessed. Cronbach's alpha coefficients for all scales exceeded the conventional benchmark of 0.70, demonstrating satisfactory internal consistency as shown by Table 1. Specifically, Technological Context (α = 0.83), Organizational Context (α = 0.87), Environmental Context (α = 0.81), and 4IR Utilisation (α = 0.85) exhibited strong reliability.

4.3. Assumptions Testing

To ensure the robustness of subsequent regression analyses, key statistical assumptions were evaluated. The Shapiro-Wilk test (P = 0.12) indicated that the residuals did not significantly deviate from normality. Visual inspection of residual scatterplots suggested homoscedasticity, while multicollinearity diagnostics yielded variance inflation factor (VIF) values ranging between 1.12 and 1.56, well below the conservative cut-off of 5 as shown by Table 2. Collectively, these results confirm the adequacy of the measurement model for hypothesis testing.

Having established the validity, reliability, and statistical adequacy of the measurement model, the study proceeded to analyse the findings of the study.

Table 1: Reliability analysis

Construct	Number of items	Cronbach's alpha (α)
Technological context	8	0.83
Organizational context	10	0.87
Environmental context	7	0.81
Fourth industrial revolution utilisation	6	0.85

Source: Own formulation

Table 2: Validity and assumptions testing

Test/measure	Value	Interpretation
Kaiser-Meyer-Olkin (KMO)	0.79	Adequate sampling adequacy (>0.60)
Bartlett's test of sphericity	$\chi^2(120)=453.22$, $P<0.001$	Data suitable for factor analysis
Shapiro-Wilk Test (normality)	P=0.12	Residuals approximately normally distributed
Homoscedasticity (Visual Check)	No pattern observed	Equal variance assumption met
Variance inflation factor (VIF)	1.12-1.56	No multicollinearity concern (<5)

Source: Own formulation

Table 3: Demographic data

Demographic variable	Category	Frequency	Percentage
Stakeholder Group	University administrators	25	15
	Faculty members	57	35
	IT and Technical Staff	33	20
	Students	48	30
Gender	Male	85	52
	Female	78	48
Age Group	Below 24 years	52	32
	25-40 years	46	28
	41-55 years	49	30
	Over 55 years	16	10
Educational qualification	A level	48	30
	Bachelor's degree	32	19
	Master's degree	65	40
	Doctoral degree	18	11
Experience with 4IR Tech	Moderate-high familiarity	114	70
	Low-no familiarity	49	30

Source: Own formulation

Table 4: Descriptive statistics on the determinants

Determinant	n	Mean	Standard deviation	Skewness
Technology infrastructure	163	3.61	0.907	–0.69
Compatibility with existing systems	163	3.48	0.592	1.94
Complexity of use	163	1.48	0.863	2.46
Reliability and security	163	1.51	0.694	2.32
Accessibility for users	163	3.2	1.422	–0.44
Technological awareness and exposure	163	1.98	1.947	–1.90
Financial resources	163	3.76	1.648	–1.77
Human resource capacity and digital skills	163	1.65	0.863	1.54
Organisational culture and openness to innovation	163	1.51	0.954	6.17
Policies and guidelines on technology use	163	1.51	0.694	7.32
Government policy and regulation (Education 5.0)	163	3.51	0.694	7.32
Innovation capacity	163	1.65	0.863	1.54
Cost of broadband	163	3.87	1.757	–1.72
Socio-economic context (economic stability, resource availability)	163	3.27	1.322	–0.64

Source: Own formulation

Table 5: Regression model summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate	F	Significance
1	0.55	0.302	0.281	0.476	32.47	<0.001

Dependent variable: Util_4IR (Utilisation of 4IR)

4.4. Demographic Data

The sample comprised 163 respondents from seven Zimbabwean state universities, encompassing university administrators (15%), faculty members (35%), IT and technical staff (20%), and students (30%) (Table 3), demonstrating a well-rounded and representative sample critical for robust quantitative study (Creswell and Poth, 2018). The gender distribution was balanced (52% male, 48% female). Gender balance is nearly equal (52% male, 48% female), aligning with best practices for inclusivity in educational research (Bryman, 2016). The age range is broad, with a substantial number of younger participants below 24 years (32%) and experienced professionals aged 41-55 years (30%), providing a dynamic mix of emerging and established viewpoints that enrich data quality (Patton, 2015). Educational qualifications varied, with 30% holding Advanced Level (high school) certificates, 19% bachelor's degrees, 40% master's degrees, and 11% doctoral degrees, indicating a predominantly well-educated cohort capable of engaging critically with technological issues (Mertens, 2014).

Importantly, 70% of respondents reported moderate to high familiarity with 4IR technologies, supporting a knowledgeable sample well-positioned to provide substantive insights into adoption dynamics. However, analysis revealed significant disparities in access to digital resources: IT staff reported substantially greater access compared to students, underscoring the existence of a digital divide within institutions. This variability has implications for institutional readiness and equity in technology utilisation.

4.5. Determinants of Fourth Industrial Revolution

Descriptive statistics for the determinants of 4IR adoption are presented in Table 4, interpreted through the TOE framework lens. During data preparation, some closely related survey items were conceptually and statistically merged to enhance parsimony and reduce redundancy. For example, within the Technological Context, eight original items were consolidated into six broader indicators (for instance, items on data privacy and system reliability were aggregated into the construct Reliability and Security). This approach aligns with best practices in measurement model refinement, where conceptually overlapping items are combined to improve clarity and interpretability of results (Hair et al., 2019).

4.5.1. Technological context

Technology Infrastructure (M = 3.61, SD = 0.91) is widely recognized as a critical enabler, affirming the importance of reliable networks and up-to-date hardware/software for 4IR integration (International Monetary Fund, 2020). Compatibility with existing old systems (M = 3.48) also ranks moderately high, though positive skewness indicates ongoing challenges

Table 6: Hypothesis path testing

Hypothesis No.	Path	β (Unstd. coefficient)	Standard errors	β (standard coefficient)	T-value	P-value	VIF	Decision
H_1	Tech_factors↓Util_4IR	0.42	0.08	0.38	5.25	<0.001	1.56	Accepted
H_2	Org_factors↓Util_4IR	0.35	0.07	0.33	4.86	<0.001	1.45	Accepted
H_3	Env_factors↓Util_4IR	0.29	0.09	0.27	3.22	0.001	1.12	Accepted

Note: Significant at P<0.05, and P<0.01 (one-tailed test). VIF<5 indicates no multicollinearity concerns. Tech_factors=Technological factors; Orgz_factors=Organisational factors; Env_factors=Environmental factors; Util_4IR=Utilisation of 4IR

in integrating older technologies a common barrier noted in literature (Zishiri et al., 2024). Conversely, Complexity of Use (M = 1.48) and Reliability and Security (M = 1.51) registered low means and high positive skewness, reflecting usability concerns and trust deficits that hinder adoption (Chatterjee et al., 2021; Phaphoom et al., 2017). Accessibility (M = 3.20) shows moderate agreement but high variability, revealing digital divides across user groups. Furthermore, the strong negative skewness suggests some outliers with high awareness but a general tendency towards low technological literacy, corroborating findings on skills deficits as major adoption barriers in resource-constrained environments (Lubinga et al., 2023).

4.5.2. Organisational context

Financial Resources (M = 3.76) emerged as the strongest enabler, widely acknowledged as essential for technology acquisition, maintenance, and capacity development (Chiwodza et al., 2023). However, Human Resource Capacity and Digital Skills (M = 1.65), Organisational Culture and Openness to Innovation (M = 1.51), and Policies and Guidelines on Technology Use (M = 1.51) scored low with extreme positive skewness, indicating entrenched institutional inertia, insufficient capacity-building, and weak governance structures. Innovation Capacity was similarly low (M = 1.65), suggesting limited institutional willingness to experiment with new technologies, consistent with documented leadership and cultural challenges in digital transformation (Singaram and Mayer, 2022; Zishiri et al., 2024).

4.5.3. Environmental context

Government Policy and Regulation (Education 5.0) exhibited a moderate mean (M = 3.51) but extreme skewness, highlighting divergent engagement with national digital strategies among universities (Kasambuwa and Pasipamire, 2025). This polarisation indicates that while some institutions align well with national digital transformation strategies, others lag behind due to varying degrees of policy engagement and institutional capacity (Mabwe and Mabhanda, 2023). Broadband Cost (M = 3.87) was identified as a significant barrier, emphasizing affordability issues affecting equitable access to digital resources. The Socio-economic Context (M = 3.27) reflects the constraints imposed by macroeconomic instability and resource scarcity on sustainable technological integration.

4.6. Inferential Analysis on TOE Framework and 4IR Utilisation

A multiple regression analysis was conducted to examine the predictive power of technological, organisational, and environmental factors on 4IR utilisation. The model was statistically significant, $F(3,159) = 32.47$, $P < 0.001$, and explained 28.1% of the variance in utilisation (Adjusted $R^2 = 0.281$), confirming that the three TOE dimensions are important determinants of adoption outcomes.

The regression results show that all three TOE dimensions significantly and positively predict the utilisation of 4IR technologies in Zimbabwean state universities as presented in Table 5 above. Among them, technological factors exerted the strongest effect ($\beta = 0.38$, $P < 0.001$) as depicted in Table 6, underscoring the central role of infrastructure readiness, system compatibility, and perceived ease of use. This aligns with findings by Mhlanga and Beneke (2021), who highlighted internet access and reliable electricity as key facilitators. Organisational factors ($\beta = 0.33$, $P < 0.001$) followed closely, highlighting the importance of institutional culture, leadership, and internal capacity-building. Environmental factors ($\beta = 0.27$, $P = 0.001$) also contributed significantly, indicating that policy support, funding, and regulatory environments remain influential. Collectively, these findings confirm that while technological readiness is foundational, sustainable adoption of 4IR requires coordinated organisational transformation and supportive external environments.

This comprehensive analysis, grounded in the TOE framework, reveals that Zimbabwean state universities face a complex interplay of enablers and barriers to 4IR adoption. While technological infrastructure and financial resources are broadly acknowledged as foundational, significant internal challenges persist related to human capital, organisational culture, and governance. Environmental factors further complicate adoption, with policy fragmentation and infrastructural costs limiting equitable access. These findings advocate for integrated, multi-level strategies that simultaneously invest in infrastructure, develop digital skills, cultivate innovation-friendly organisational cultures, and streamline policy frameworks. Such an approach is essential to harness the transformative potential of 4IR technologies for enhancing teaching, research, and institutional effectiveness, thereby contributing to national development goals in the digital era.

5. CONCLUSION

This study investigated the determinants influencing the utilisation of 4IR technologies in Zimbabwean state universities using the TOE framework. Quantitative data from 163 respondents across seven universities revealed that technological, organisational, and environmental factors all significantly influence 4IR adoption. Technological readiness, characterized by ease of use, accessibility, and perceived usefulness, emerged as the strongest predictor of utilisation. Organisational elements such as strategic leadership, institutional support, and an innovation-oriented culture also played critical roles. Environmental factors, including coherent policy frameworks and engagement with external stakeholders, further shaped technology integration, albeit to a lesser extent. Despite respondents' advanced qualifications and familiarity with 4IR concepts, notable gaps were identified, including disparities in digital access between staff and students, institutional resistance to change, uneven faculty capacity, and fragmented policy implementation. These challenges risk widening the digital divide within Zimbabwe's higher education sector unless addressed through deliberate, equity-focused strategies.

Effective integration of 4IR technologies demands a multifaceted approach: investing in resilient, scalable infrastructure to ensure equitable access; strengthening leadership commitment and fostering innovation-friendly institutional cultures through targeted training and capacity building; and implementing clear, consistent policies while fostering public-private and

international partnerships. Beyond technological upgrades, this transformation requires embedding digital innovation into institutional frameworks and aligning policies with national development priorities. Only through such comprehensive efforts can Zimbabwean state universities bridge existing divides and emerge as drivers of innovation and socio-economic progress. The opportunity to lead Africa's digital transformation is within reach, but success hinges on coordinated, sustained action to fully harness the transformative potential of 4IR technologies in higher education.

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